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Pyrolysed carbon resonators – Fabrication and characterization

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This work presents the fabrication and the mechanical characterization of bimaterial membranes made of pyrolysed carbon (pC) and silicon nitride (SiN) in order to evaluate the intrinsic losses present in such carbon-based materials.

SiN membranes have emerged as promising resonators for precision sensing and quantum mechanical fundamental studies [1]. Intrinsic tensile stress of stoichiometric Si_3N_4 is large and results in extremely high quality factors (Q of several million) at room temperature and Q-frequency products of above 10^{13} Hz [2, 3]. It is possible to combine SiN membranes with other materials, e.g. adding a metal [4] or graphene [5, 6] layer in order to implement a electrical transduction. Pyrolysed carbon (pC) offers an intriguing alternative. Pyrolysed carbon shows outstanding mechanical [7] and electrical properties [8], chemical inertness towards a wide variety of solvents and electrolytes, high-temperature stability, and wide electrochemical potential window for electrochemical applications. Since pC electrodes can be readily fabricated from photo-patternable polymers, it is possible to obtain carbon micro- or nanostructures without restrictions in shape and cross section, where the feature size is limited by e.g. top-down lithography techniques.

In this study we explore the possibility of integrating pC layers with different thicknesses on high-Q SiN membranes to exploit the combination of their mechanical and electrical properties for future sensing applications.

200nm thick membranes of Si_3N_4 with a lateral size of 1x1 mm^2 and 0.5x0.5 mm^2 were fabricated. Three different thicknesses of SU-8 (negative photoresist and carbon precursor in this work) were spin coated onto the SiN membranes and lithographically processed. A pC layer was obtained from pyrolysis of the SU-8 membranes at 900 °C in nitrogen atmosphere (Fig. 1). Membranes with 5 different configurations were tested: 1) bare membranes, 2) membranes annealed at 900 °C without pC, 3) with 0.2 µm pC, 4) with 0.5 µm pC, and 5) with 1.5 µm pC. For characterization, the membranes were actuated with a piezo in high vacuum (below 10^{-5} mbar) and the vibration was readout optically with a laser-Doppler vibrometer (Polytec MSA-400). The quality factor and resonance frequency (f_r) of the 9 lowest symmetrical modes were derived from the particular resonance peak, measured with a lock-in amplifier (Zurich Instruments HF2).

Fig. 3 shows the measured Qs and damping rates (f_r/Q) of the 0.5x0.5 mm^2 and 1x1 mm^2 membranes with different pC layer thicknesses. The quality factor is higher for the larger membranes, which is in accordance to theory [3]. But there is no significant difference between the bare SiN and the bare annealed SiN membranes. For both membrane sizes the Q was higher as the pC layer got thinner. This is a result of the lower damping rate of thinner pC layers, due to higher internal losses of pyrolysed carbon compared to SiN. However, the Q values of pC membranes are more than 3 orders of magnitudes higher than with unpyrolysed polymer. Membranes with SU-8 displayed quality factors of the order of 10. As originally expected, pyrolysis significantly reduces the high intrinsic material losses of SU-8.

Pyrolysed carbon layers are easy to micro-pattern, have a good conductivity, and have significantly reduced mechanical losses compared to unpyrolysed polymers. This implies that pC layers are excellent and versatile electrodes for future applications that combine mechanical and electrical sensing.

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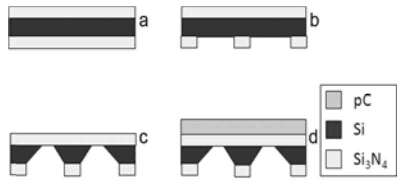

Figure 1. Fabrication process flow for the pyrolysed carbon membranes. A layer of LPCVD stoichiometric Si_3N_4 is deposited on silicon (Si). The Si_3N_4 layer is then patterned on the backside (b) to define the windows for the subsequent Si anisotropic etching with KOH (c). Next, a layer of SU-8, precursor of the pyrolysed carbon layer (pC), is deposited and processed (d).

Figure 2. Micrograph picture of the pyrolysed carbon membrane. Membranes were stuck to a piezoelectric ceramic support for an actuation based on physical shaking of the chips.

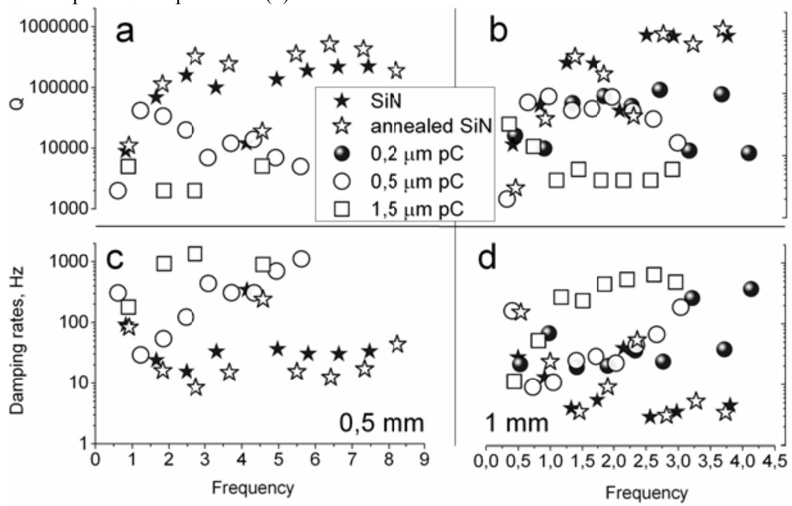

Figure 3. Quality factor (Q) and damping rates vs frequency of 0.5x0.5mm^2 (a & c) and 1x1mm^2 (b & d) membranes, respectively, for different pC layer thicknesses.